# The Lakes of Maple Valley and Covington

Water Quality Monitoring Results for
Water Year 2015 at Lake Lucerne, Pipe Lake, and Lake Wilderness

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King County

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## Water Quality Monitoring Results for Water Year 2015 at Lake Lucerne, Pipe Lake, and Lake Wilderness

**Prepared for:**

The Cities of Covington and Maple Valley

**Submitted by:**

Department of Natural Resources and Parks
King County Water and Land Resources Division

The King County Lake Stewardship Program

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# Acknowledgements

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# EXECUTIVE SUMMARY


The King County Lake Stewardship Program works with lakeside resident volunteers to monitor water quality and lake use for lakes Lucerne, Pipe, and Wilderness located within the cities of Maple Valley and Covington. Lake Lucerne data has been collected since the 1980s, while Pipe and Wilderness Lakes have been monitored since the 1970s. Since 2005, the cities of Maple Valley and Covington have funded participation in the Lake Stewardship Program through interagency agreements with King County. During the 2015 water year, volunteers measured precipitation, lake level, temperature, and Secchi transparency year-round. Water quality samples were collected at all three lakes from May through October.

Water quality data indicate that Lake Lucerne and Pipe Lake are classified as oligotrophic, and exhibit low algal productivity, with low concentrations of chlorophyll-*a* measured in the water column throughout the sample season. Lake Wilderness is classified as mesotrophic-eutrophic, with moderate algal productivity. While chlorophyll-*a* concentrations were low at times during the sample season in Lake Wilderness, the lake also experienced periods of high algal growth. Nitrogen-to-phosphorus (N:P) ratios in both Lake Lucerne and Pipe Lake indicate phosphorus limitation, while Lake Wilderness shows periods of possible nitrogen limitation or co-limitation. Nitrogen limitation can be favorable to cyanobacteria (blue-green algae), which can produce toxins under certain conditions.

Lake Wilderness has experienced several toxic cyanobacteria blooms since toxin monitoring began there in 2008, with microcystin concentrations above the WA State Recreational Guidance threshold in 2009, 2010, 2013, and 2015. We recommend continuing to pay close attention to N:P ratios in Lake Wilderness, which have been increasing over time and favoring potentially toxic cyanobacteria.

Thermal stratification was present in all three lakes in both May and August. Temperature patterns over the course of the May-October sample season were also similar among the lakes, with water warming through mid-July and cooling thereafter. Lake Lucerne and Pipe Lake were quite clear, with some of the deepest Secchi readings of the 36 lakes monitored in King County. Lake Wilderness experienced greater variability in Secchi depth. All three lakes had little coloring from dissolved organic substances.

A great deal of information about the water quality in lakes Lucerne, Pipe, and Wilderness has been collected over the years of monitoring. Overall, all three lakes appear to be healthy. The Lake Stewardship Program continues to be successful in monitoring water quality in the lakes, supporting the enthusiastic participation of volunteer monitors, and maintaining interest in lake health among lakeside residents.

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# 1.0 PROGRAM OVERVIEW

The Lake Stewardship Program has been working with volunteers to monitor Lake Lucerne, Pipe Lake, and Lake Wilderness for over 30 years. Beginning in 2005, the cities of Maple Valley and Covington established an agreement with King County to continue the volunteer monitoring program when county funding was reduced. This agreement has allowed monitoring efforts to continue through the present, with the help of dedicated resident volunteers.

At Lake Lucerne, a small number of samples were collected in the 1970s; consistent monitoring began in the 1980s and has continued through the present, with only one data gap in the early 1990s. Volunteer monitoring also began at Pipe Lake in the 1970s and has been continuous since the early 1990s. Monitoring began at Lake Wilderness in the mid-1970s and has continued through the present, with few gaps in the record. Both Lakes Lucerne and Wilderness are located entirely in the city limits of Maple Valley. Approximately 55% of the shoreline of Pipe Lake is in Maple Valley; the remainder is in the City of Covington.

Of the three lakes, Wilderness was the only lake with an active Level I volunteer monitor. Level I volunteers collected lake level and precipitation data on a daily basis year-round. Additionally, weekly measurements were collected for water temperature and Secchi depth (water clarity). The main emphasis of the effort was to observe the hydrological balance between the lake and its watershed, as well as annual temperature ranges and fluctuations in water clarity. Daily Level I measurements were collected at lake-side docks, and weekly measurements were taken at a mid-lake sampling station located at the deepest point in the lake.

Level II monitoring occurred on a twice-monthly basis from May through October at all three lakes. In addition to measuring water temperature and Secchi depth, Level II volunteers also collected water samples to be analyzed at the King County Environmental Laboratory (KCEL) for various chemical parameters. The main emphasis in this effort was to quantify nutrient balances and algal concentrations in the lake. Level II monitoring was also collected at a mid-lake sampling station at the deepest point in the lakes. Both Level I and Level II volunteers routinely made observations regarding recreational lake use, algal blooms, and special weather conditions that may have had an effect on measurements.

Volunteers were provided with training, equipment, and technical assistance on an ongoing basis. They were also offered the option of attending the annual Lake Stewardship Program training workshop held in late April. Level I data were reported to King County on a quarterly basis for quality control assessment and uploaded to the Small Lakes Data and Information webpage (http://green2.kingcounty.gov/SmallLakes). Level II water samples collected by volunteers were routinely picked up by Lake Stewardship staff for delivery to KCEL, and data was analyzed and uploaded to the web upon receipt from the lab.

Specific objectives of the monitoring program include: (1) gathering baseline data with the intent of assessing long-term trends; (2) defining seasonal and water column variability; (3) identifying potential concerns, and proposing possible management solutions when feasible; (4) educating lake residents, lake users, and policy makers regarding lake water quality; and (5) providing a foundation of understanding the nature and character of the smaller lakes in King County.

# 2.0 WHAT WE MEASURE AND WHY

**Precipitation** is measured using a plastic volumetric rain gauge mounted in an open area. This data is collected daily by Level I volunteers and is used to relate precipitation to lake level.

**Lake level** is tracked by Level I volunteers using a staff plate mounted to a fixed dock or other structure. This information is used to track water level changes both seasonally and over time and can be related to precipitation levels in the basin, as well as potential groundwater inputs.

**Secchi depth**/transparency is a common method used to assess and compare water clarity over time. It is a measure of the water depth at which a black and white disk disappears from view when lowered from the water surface. Readings can be affected by suspended particles in the water, such as sediment or algae. Secchi depth measurements were collected at a mid-lake sampling station every other week from May through October (Level II volunteers), and on a weekly basis throughout the year (Level I volunteers).

**Water temperature**, as with Secchi depth, is measured by Level I volunteers year-round, and by Level II volunteers from May through October at a depth of 1 meter. On two occasions during the Level II sample season, temperature is measured at additional depths from the mid-lake station (water column profile). Temperature is important in many biological processes in a lake, can affect rates of plant and algal growth, and can create or inhibit ideal habitat for fish and other aquatic life.

**Phosphorus** and **nitrogen** are naturally occurring elements; these nutrients are necessary for growth and reproduction in both plants and animals. However, many activities associated with residential development can increase these nutrients in water beyond natural concentrations. In lakes of the Puget Sound lowlands, phosphorus is often the nutrient in least supply, meaning that biological productivity is most often limited by the amount of available phosphorus in the water. Increases in phosphorus can lead to more frequent and dense algae blooms – a nuisance to residents and lake users, and a potential safety threat if blooms become dominated by cyanobacteria (blue-green algae) that can produce toxins.

Samples to be analyzed for total phosphorus (TP) and total nitrogen (TN) were collected by Level II volunteers at a depth of one meter at the mid-lake station during the months of May through October. Samples from additional depths were collected in May and August (water column profiles).

The **ratio of total nitrogen to total phosphorus (N:P)** can be used to determine if nutrient conditions are favorable for the growth of cyanobacteria. When N:P ratios are near or below 25, nitrogen is as likely as phosphorus to be the nutrient limiting algal growth.

Certain cyanobacteria species may then be able to dominate the algal community due to their ability to "fix" nitrogen (convert it to a form more easily utilized for nutrition).

**Chlorophyll-*a*** concentration serves as an indicator of the abundance of phytoplankton (algae) in a lake. Chlorophyll-*a* is a pigment that is necessary for algae to photosynthesize and store energy. While all algal cells contain some chlorophyll-*a*, the amount varies depending on the species. For example, some cyanobacteria have other light-catching pigments, and little chlorophyll-*a* compared to other planktonic species, so chlorophyll-*a* concentrations may not always correlate with the abundance of cyanobacteria.

**Pheophytin** is a product of chlorophyll decomposition and is generally measured along with chlorophyll-*a* as an indicator of how fresh or viable the phytoplankton in the sample are. Bottom sediments will contain a large amounts of pheophytin compared to chlorophyll-*a*, while actively-growing algae from the water column will have very little pheophytin present.

Chlorophyll-*a*/pheophytin samples were collected at a depth of 1 meter at the mid-lake station from May through October, and at additional depths in May and August (water column profiles).

A common method of tracking water quality trends in lakes is by calculating the **Trophic State Index (TSI)**, developed and first presented by Robert Carlson (1977). TSI values predict the biological productivity of the lake based on three parameters: water clarity (Secchi), total phosphorus, and chlorophyll-*a.* The values are scaled from 0 to 100, which allow them to be used for comparisons of water quality over time and among lakes. If all of the assumptions about a lake ecosystem are met, the three TSI values should be very close together for a particular lake. When they are far apart in value, lake conditions and measurements should be examined to understand what special conditions exist at the lake that are different from Carlson's assumptions, or if data should be evaluated for errors. The index assumes that higher nutrient availability equates to more phytoplankton production, and more phytoplankton particles in the water lead to decreased clarity, and vice versa.

The Index relates to three commonly used categories of productivity:

- *oligotrophic* (low productivity, below 40 on the TSI scale – low in nutrient concentrations, small amount of algae growth);
- *mesotrophic* (moderate productivity, between 40 and 50 on TSI scale – moderate nutrient concentrations, moderate growth of algae growth); and
- *eutrophic* (high productivity, above 50 – high nutrient concentrations, high level of algae growth).

A lake may fall into any of these categories naturally, depending on the conditions in the watershed, climate characteristics, vegetation, rock and soil types, as well as the shape and volume characteristics of the lake basin. Activities of people, such as land development, wastewater systems, and agricultural practices can also increase productivity, which is known as "cultural eutrophication."

On two occasions during the summer sampling season, water is collected from three depths at the mid-lake sampling station: 1 meter, the middle depth of the water column, and 1 meter from the lake bottom. These **water column profiles** provide information about how temperature, nutrients, and other variables change at different depths during periods when the lake is thermally stratified. Additional parameters are also measured during these profile events including ammonia ($NH_3$), nitrate/nitrite ($NO_2$/$NO_3$), orthophosphate ($OPO_4$), alkalinity, and water color (UV254). Ammonia, a form of nitrogen, is often found in deep water at higher concentrations when oxygen is low, as are nitrate/nitrite and orthophosphate. Total alkalinity illustrates the buffering capacity of a lake, or the ability to resist changes in pH. UV254 is the wavelength at which dissolved organic molecules absorb light and is used to measure the amount of color in the water related to organic compounds.

# 3.0 LAKE LUCERNE RESULTS

## 3.1 Secchi Depth

Secchi depth in Lake Lucerne ranged from 5.0 to 9.5 meters during the 2015 water year, with an average of 6 meters from May through October (Figure 1, note that the y-axis is traditionally reversed on Secchi charts to mimic looking into the water from the lake surface). The shallowest Secchi depths were recorded in October, possibly as a result of late fall algae blooms.

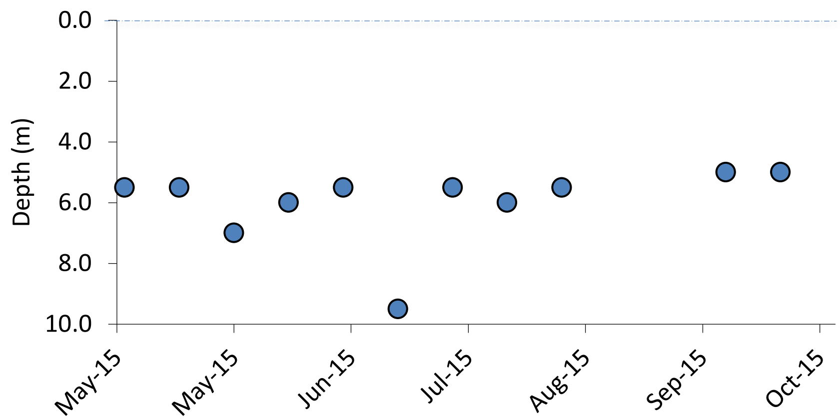


**Figure 1. Secchi transparency for Lake Lucerne, water year 2015. Note the inverted Y-axis.**

## 3.2 Water Temperature

Water temperature was measured at a depth of 1 meter from May through October. Water temperature ranged from 17.0°C to 25.5°C, with an average of 22.1°C (Figure 2). Water temperature rose through mid-July, and steadily declined through mid-October. The highest temperature observed during the sample season was recorded during the last sample event on October 18th.

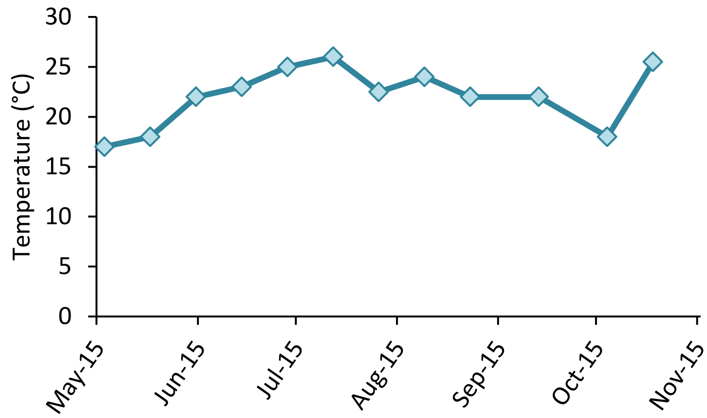


**Figure 2. Level II water temperature at 1 m for Lake Lucerne, May-October 2015.**

The average water temperature measured in 2015 was slightly higher than in 2014 (Figure 3). There have been numerous increasing and decreasing fluctuations in the data since 1996. When a linear trend line is applied to the data, he R-squared value of 0.0378 indicates that the line is a weak fit for the data (R-squared values close to one indicate a better line fit). Further monitoring will help determine if water temperatures in Lake Lucerne are rising or falling over time.

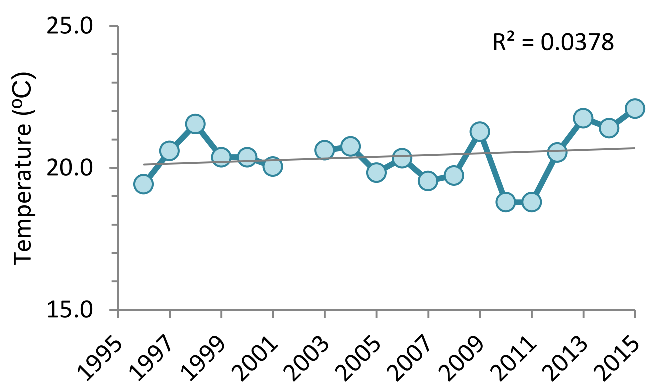


**Figure 3. Average water temperature at 1 m for Lake Lucerne, May-October, 2015.**

## 3.3 Total Phosphorus and Total Nitrogen

Total phosphorus concentrations remained relatively stable in Lake Lucerne, while total nitrogen concentrations exhibited some fluctuations throughout the sample season (Figure 4). There was a noticeable peak in total nitrogen in mid-September. Total nitrogen concentrations ranged from 227-563 µg/L, with an average of 338 µg/L. Total phosphorus concentrations ranged from 5.2 to 13.4 µg/L, with a mean value of 8.4 µg/L.

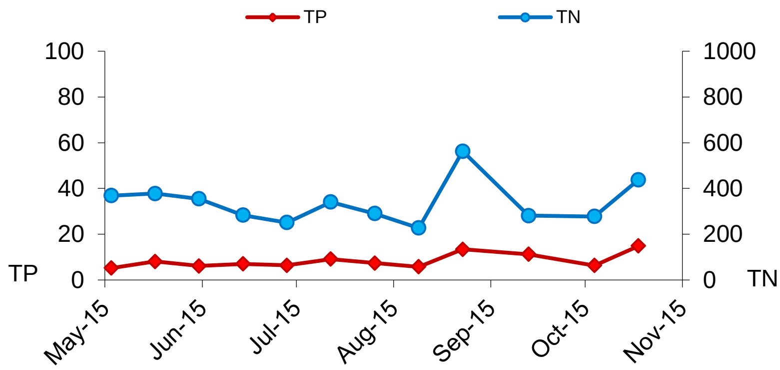


**Figure 4.** **Lake Lucerne total phosphorus and total nitrogen in µg/L, May-Oct 2015.**

The ratio of total nitrogen to total phosphorus (N:P ratio) in Lake Lucerne from May through October of 2015 ranged from 25.1 to 71.0, with an average ratio of 42.7 (Figure 5). For the majority of the sample season, the N:P ratio was at or above 25, indicating that phosphorus was most likely limiting phytoplankton production, and nutrient conditions were not favorable for cyanobacteria blooms.

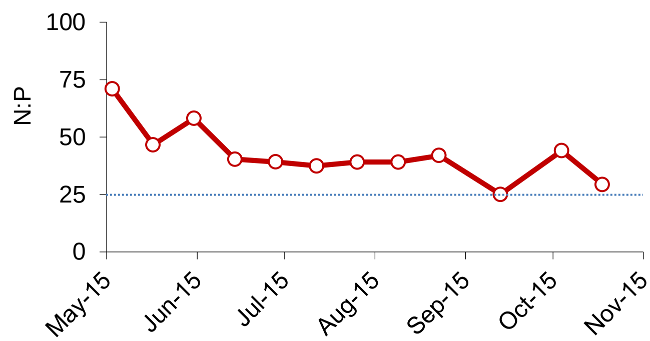


**Figure 5.** **Lake Lucerne N:P ratios, May-October 2015.**

Average N:P ratios over time ranged from 33.1 to 51.2 in Lake Lucerne (Figure 6). When a linear trend line is applied to the data, there does not appear to be either an increasing or decreasing trend over time. The R-squared value of 0.035 indicates that the line is a poor fit for the data. Average N:P values have always been above 25, indicating that Lake Lucerne has been primarily phosphorus-limited over time.

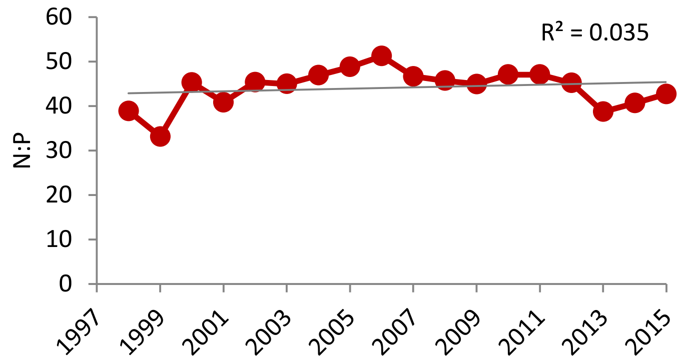


**Figure 6. Average May though October N:P ratios for Lake Lucerne since 1998.**

## 3.4 Chlorophyll-*a*

Concentrations of chlorophyll-*a* in Lake Lucerne were low throughout the sample season, with a small peak in mid-October (Figure 7). Concentrations ranged from 1.0 µg/L to 5.11 µg/L, with an average of 1.96 µg/L. Of the 36 lakes monitored in 2015, Lake Lucerne had the second-lowest average chlorophyll-*a* value. Pheophytin concentrations remained below detection limits for nearly the entire sample season, indicating that the samples were fresh and stored properly.

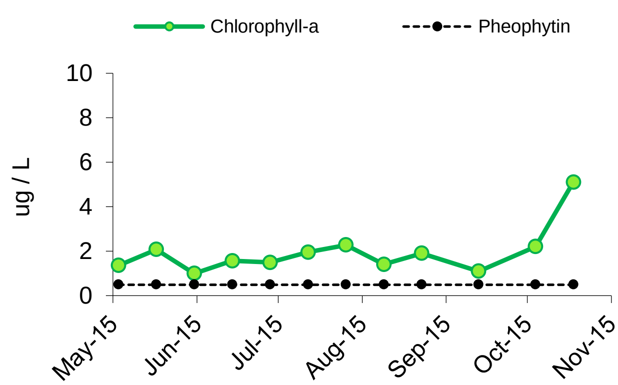


**Figure 7. Chlorophyll-*a* and pheophytin concentrations for Lake Lucerne, May-October 2015.**

## 3.5 Trophic State Indices

In 2015, all three trophic state indicators were in the oligotrophic range for Lake Lucerne (Figure 8). Additionally, the three indices were close together on the scale, indicating that the relationships between phosphorus, the amount of phytoplankton in the lake, and water clarity were typical of what the index would predict.

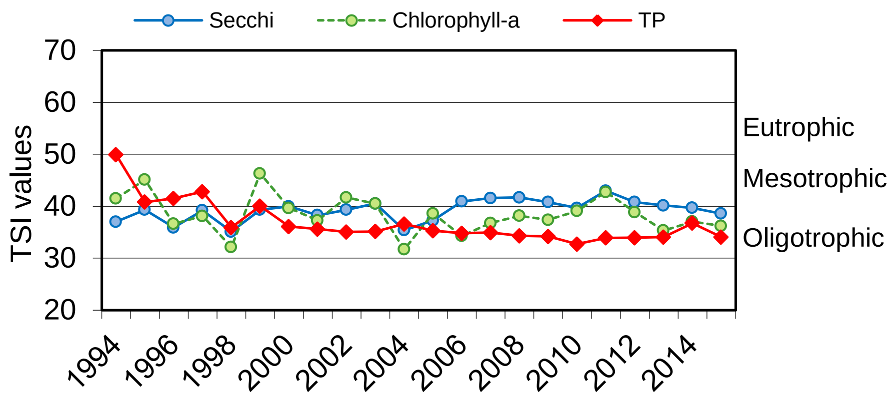


**Figure 8. Average May-October Trophic State Indicators for Lake Lucerne, 1994-2015.**

## 3.6 Water Column Profiles

Temperature data in Lake Lucerne indicate that thermal stratification (layering of warm, shallow water over cooler water at greater depth) was present in May and persisted through the second profile sampling event in late August (Table 1). Concentrations of total phosphorus were elevated in the deepest sample for both the May and August profile events. Orthophosphate ($OPO_4$) concentrations were not elevated at depth, indicating little release of phosphorus from the sediments into the lake. Ammonia ($NH_3$) values were lower in the deeper water than in the epilimnion (surface waters) also indicating little sediment release of nutrients during stratification. Chlorophyll-*a* data indicate that algae were present in the water column, and at slightly higher concentrations below the surface at 5 meters.

**Table 1. Lake Lucerne water column profile results, 2015.**

| Date | Secchi | Depth | Temp | Chl-a | Pheo | TN | $NO_{2/3}$ | $NH_3$ | TP | $OPO_4$ | Alk | UV254 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/14/15 | 6 | 1 | 23 | 1.57 | *0.5* | 0.283 | 0.017 | 0.0147 | 0.007 | 0.0011 | | |
| | | 5 | 17 | 2.93 | *0.5* | 0.248 | | | 0.0067 | | | |
| | | 9 | 8 | | | 0.498 | *0.005* | 0.0047 | 0.0417 | 0.0018 | | |
| 8/23/15 | 6 | 1 | 22 | 1.91 | *0.5* | 0.563 | *0.005* | 0.0118 | 0.0134 | 0.00369 | 33 | 0.0752 |
| | | 4.5 | 22 | 2.00 | *0.5* | 0.297 | | | 0.0059 | | | |
| | | 9 | 12 | | | 0.579 | *0.005* | 0.0041 | 0.0575 | 0.002 | | |

Note: Temperature in degrees Celsius. Chlorophyll-*a* and pheophytin in µg/L. TN, $NO_{2/3}$, $NH_3$, TP, $OPO_4$, and alkalinity in mg/L. UV254 is in absorption units. Sample values below minimum detection level (MDL) are highlighted in red italics and have the value of the detection limit substituted.

UV254 is the wavelength at which dissolved organic molecules absorb light and is used to measure the amount of color in the water due to organic compounds. The low UV254 absorption values indicate that the water in Lake Lucerne was very lightly colored by dissolved organic substances. Total alkalinity was moderately low, indicating that the water was only lightly buffered against changes in pH, and thus is potentially more sensitive to acidification.

## 3.7 Conclusions

Water quality parameters in Lake Lucerne have fluctuated over the sampling years of 1994–2015, similar to the behavior of most aquatic systems in responding to multiple and diverse environmental variables. Measurements of physical and chemical parameters have varied from year to year with no evident upward or downward trends.

Secchi depth measurements depict Lake Lucerne as fairly clear, with little interference from particulate matter. These results agree with UV254 measurements collected during water column profile sampling events, which indicate that Lake Lucerne has little coloration from dissolved organic substances.

The temperature pattern exhibited in Lake Lucerne over the course of the sample season was similar to that of numerous other lakes in the region in 2015, with the exception of one notably warmer measurement taken during the last sample event in October. Average temperature in the lake was slightly higher than in 2014. Average temperatures since 2013 were higher, though more years of monitoring will be necessary to determine if this is a statistically significant trend. Profile temperature data indicate that Lake Lucerne is stratified during the summer and fall.

Nutrient data depict Lake Lucerne as oligotrophic, with low algal productivity. These data agree with low chlorophyll-*a* concentrations measured in the lake throughout the sample season. N:P indicate phosphorus limitation for most of the season, with conditions that are less favorable for the growth of blue-green algae.

The long term monitoring that the volunteers at Lake Lucerne have performed since 1994 has created an impressive and useful dataset that reflects the water quality story of the lake. Continued monitoring will help build this dataset, increasing our understanding of how the lake reacts to changes in regional weather and other changes in the watershed.

# 4.0 PIPE LAKE RESULTS

## 4.1 Secchi Depth

Secchi depth in Pipe Lake ranged from 4.75 to 8.5 meters during the 2015 sample season, with an average of 6.75 meters. With the exception of one other lake, Pipe Lake had the deepest Secchi depth measurements of the 36 lakes monitored in King County in 2015.

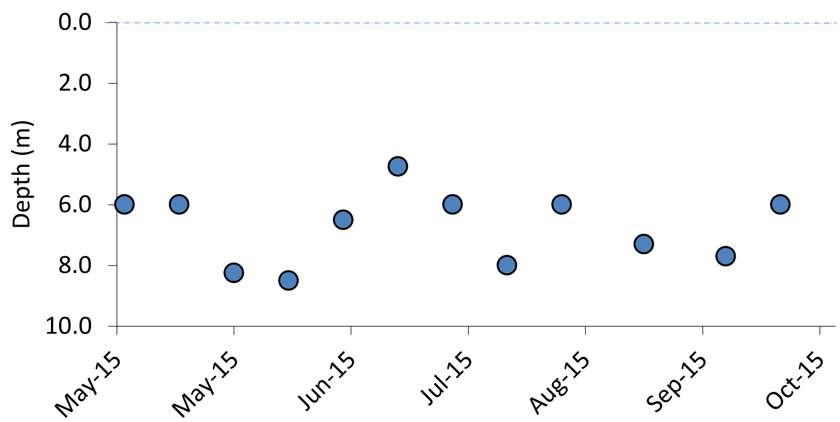


**Figure 9. Secchi transparency for Pipe Lake, water year 2015. Note the inverted Y-axis.**

## 4.2 Water Temperature

Water temperature was measured at a 1 meter depth in Pipe Lake from May through October. Temperatures ranged from 13.5°C to 26°C, with a mean water temperature of 21.8°C (Figure 10). Temperature rose gradually from May through July, then decreased as air temperatures cooled through the last sample event in October.

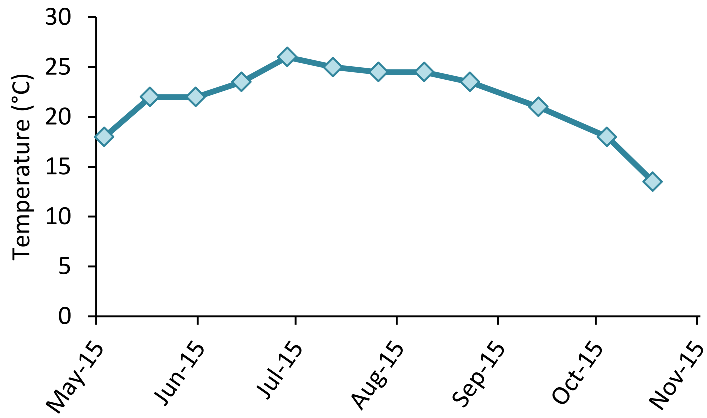


**Figure 10. Water temperature at 1 m for Pipe Lake, water year 2015.**

Average water temperature during the 2015 May-October sample season was nearly equal to 2013 and 2014 (21.3°C and 21.6°C, respectively). When a linear trend line is applied to mean temperature data, there appears to be a slight increasing trend, though an R-squared value of 0.3172 indicates moderate line fit for the data (Figure 11). Further monitoring will help determine if water temperatures in Pipe Lake are continuing to increase over time.

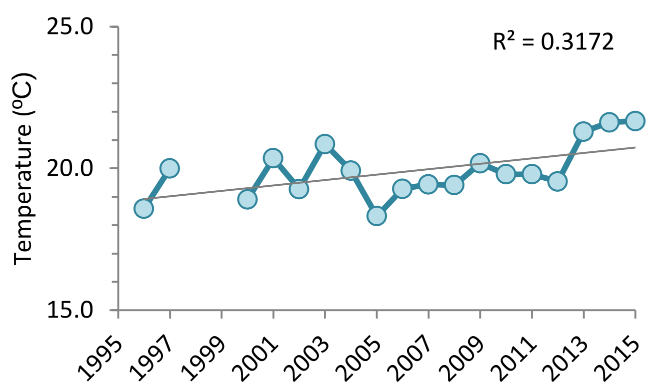


**Figure 11. Mean water temperature at 1 m for Pipe Lake, May-October 1996-2015.**

# 4.3 Total Phosphorus and Total Nitrogen

Concentrations of total phosphorus and total nitrogen in Pipe Lake remained stable throughout the sample season (Figure 12). Total nitrogen concentrations ranged from 217 to 421 µg/L, with an average of 303 µg/L. Total phosphorus concentrations ranged from 5.5 to 7.6 µg/L, with an average of 6.6 µg/L.

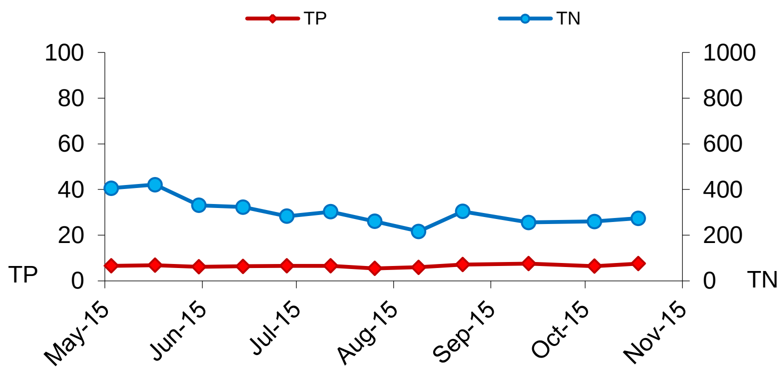


**Figure 12. Pipe Lake total phosphorus and total nitrogen in µg/L, May-Oct 2015.**

The ratio of total nitrogen to total phosphorus (N:P ratio) in Pipe Lake from May through October of 2015 ranged from 33.7 to 61.5, with an average ratio of 45.9 (Figure 13). Throughout the sample season, the N:P ratio was at or above 25, indicating that phosphorus was most likely limiting phytoplankton production, and nutrient conditions were not favorable for cyanobacteria blooms.

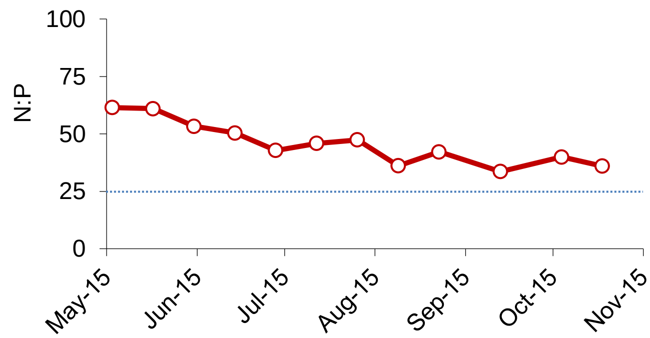


**Figure 13. Pipe Lake N:P ratios, May-October 2015.**

Average summer N:P ratios in Pipe Lake have ranged from 36.6 to 57.7 since 1998 (Figure 14). There does not appear to be either an increasing or decreasing trend over time, and an R-squared value of 0.0056 indicates a weak line fit.

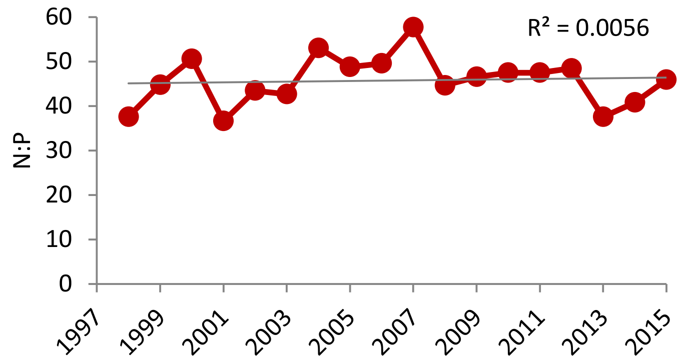


**Figure 14. Pipe Lake May-October average summer N:P ratios, 1998-2015.**

## 4.4 Chlorophyll-*a*

Chlorophyll-*a* concentrations remained low throughout the sample season in Pipe Lake (Figure 15). Chlorophyll-a concentrations ranged from 0.67 to 3.9 µg/L with an average of 2.1 µg/L. There were small increases in chlorophyll-*a* in mid-July and mid-October. Pheophytin remained below detection limits all summer, indicating that the samples were fresh and stored properly. These results agree with nutrient data that indicate algal growth in Pipe Lake was likely limited by low phosphorus concentrations.

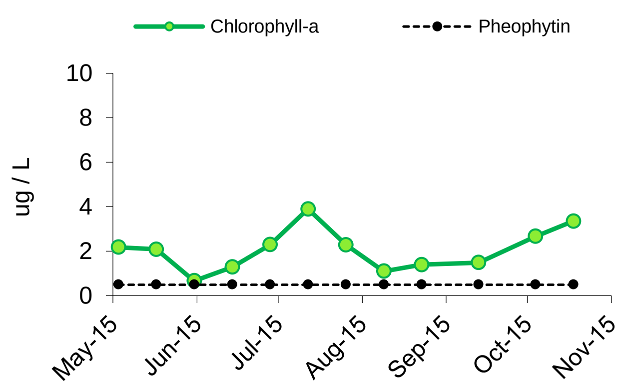


**Figure 15. Chlorophyll-*a* and pheophytin concentrations for Pipe Lake, May-October 2015.**

## 4.5 Trophic State Indices

In 2014, all three trophic indicators were in the oligotrophic range, indicating that Pipe Lake exhibited low algal productivity (Figure 16). Both the Secchi and the phosphorus TSI values decreased from 2014, while the chlorophyll-*a* value remained nearly equal. The Secchi and chlorophyll-*a* TSI values were very close together on the scale, indicating that water clarity in Pipe Lake is closely linked to the amount of phytoplankton in the water.

The phosphorus TSI was slightly lower than the other two, meaning that there was more phytoplankton in Pipe Lake than the amount predicted by Carlson's TSI model.

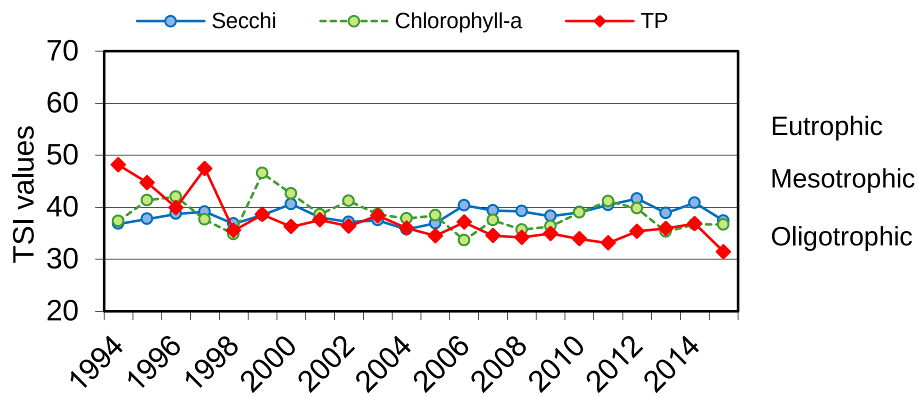


**Figure 16. Average Pipe Lake Trophic State Indicators, 1995-2015.**

## 4.6 Water Column Profiles

Thermal stratification in Pipe Lake was present during the May profile sampling event and persisted through August (Table 2). In May, there were slightly higher nutrient concentrations in the deeper water, and this was much more pronounced in August. Higher nutrient concentrations near the lake bottom indicate that nutrients were being released from the sediment into the deep water layer (hypolimnion). This release occurs when oxygen concentrations are low at the sediment-water interface.

**Table 2. Pipe Lake water column profile results, 2014.**

| Date | Secchi | Depth | Temp | Chl-a | Pheo | TN | $NO_{2/3}$ | $NH_3$ | TP | $OPO_4$ | Alk | UV254 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/17/15 | 6 | 1 | 22 | 2.09 | *0.5* | 0.421 | 0.108 | 0.0194 | 0.0069 | *0.0005* | 28.1 | 0.0762 |
| | | 10 | 8.5 | 7.53 | 1.1 | 0.491 | | | 0.0087 | | | |
| | | 19 | 7 | | | 0.532 | 0.0996 | 0.175 | 0.0359 | 0.00637 | | |
| 8.23/15 | 8 | 1 | 23.5 | 1.4 | *0.5* | 0.304 | *0.005* | 0.0057 | 0.0072 | *0.0005* | 32.2 | 0.0659 |
| | | 10 | 9 | 2.98 | *0.5* | 0.420 | | | 0.0098 | | | |
| | | 21 | 7 | | | 1.380 | *0.005* | 0.835 | 0.3670 | 0.001 | | |

Note: Temperature in degrees Celsius. Chlorophyll-*a* and pheophytin in µg/L. TN, $NO_{2/3}$, $NH_3$, TP, $OPO_4$, and alkalinity in mg/L. UV254 is in absorption units. Sample values below minimum detection level (MDL) are highlighted in red italics and have the value of the detection limit substituted.

Chlorophyll-*a* profile data indicate that algae were present in higher concentrations in mid-depth waters. This suggests that the algal species thriving in Pipe Lake at that time were able to adapt to lower light levels in order to take advantage of higher nutrient concentrations.

UV254 is the wavelength at which dissolved organic molecules absorb light and is used to measure the amount of color in the water related to organic compounds. The low UV254 absorbance values indicate that the water in Pipe Lake was fairly clear, with little coloration from dissolved organic substances. The alkalinity in Pipe Lake was low, meaning that the lake is only lightly buffered against pH changes.

## 4.7 Conclusions

Secchi depth measurements depict Pipe Lake as fairly clear, with little interference from particulate matter. With the exception of one other lake, Pipe Lake had the deepest Secchi depth measurements of the 36 lakes monitored in King County in 2015. These results agree with UV254 measurements collected during water column profile sampling events, which indicate that Pipe Lake had little coloration from dissolved organic substances.

The temperature pattern exhibited in Pipe Lake over the course of the sample season was very similar to that of numerous other lakes in the region in 2015, with temperatures warming through mid-July and afterwards decreasing for the remainder of the season. Average temperature was nearly equal to that from 2014 and 2013. There is a potential trend of increasing temperature in the lake over time, though more years of monitoring will be necessary to produce a statistically viable trend. Profile temperature data indicate that Pipe Lake was stratified during the summer and fall.

Nutrient data depict Pipe Lake as oligotrophic, with low algal productivity. These data agree with the low chlorophyll-*a* concentrations measured in the lake throughout the sample season. N:P ratios indicate phosphorus limitation, with conditions that are less favorable for the growth of blue-green algae.

The long term monitoring that the volunteers at Pipe Lake have performed since 1994 has created an impressive and useful dataset that reflects the water quality story of the lake. Continued monitoring will help build this dataset, increasing our understanding of how the lake reacts to changes in weather and other influences on the watershed.

# 5.0 LAKE WILDERNESS RESULTS

## 5.1 Lake Level and Precipitation

Throughout the 2015 water year, lake level in Lake Wilderness followed a pattern of winter highs and summer lows, similar to many other lakes in the region. Levels remained fairly stable throughout the winter, and there were not any marked responses to large precipitation events. Precipitation decreased throughout the spring, as did lake level.

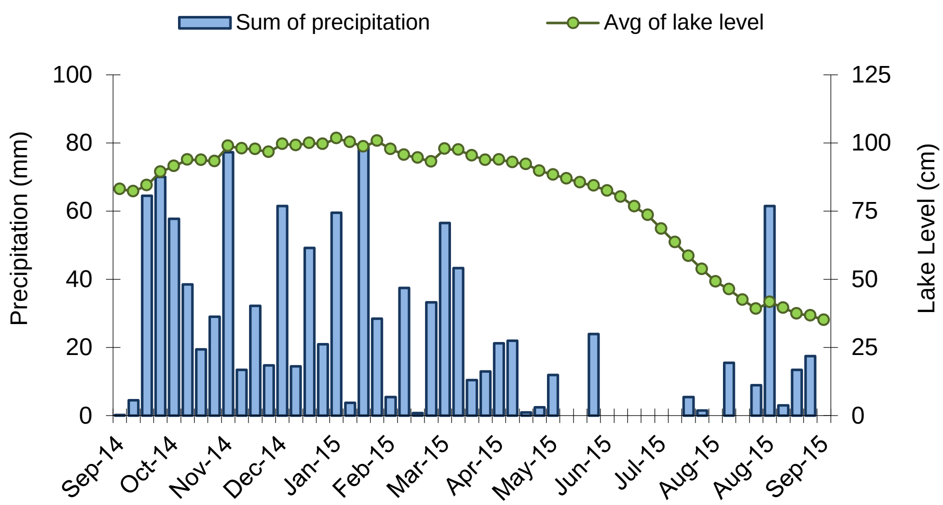


**Figure 17. Weekly mean lake level and total weekly precipitation for Lake Wilderness, water year 2015.**

## 5.2 Secchi Depth

Secchi depth varied from 1.5 to 7.5 meters over the course of the year, with an average of 4.8 meters (Figure 18, note that the Y-axis is traditionally reversed on Secchi depth charts to mimic looking into the water from the lake surface). Secchi transparency in Lake Wilderness typically follows a pattern of decreased clarity in the spring and late summer/early fall. This decrease is likely due to algal blooms that regularly occur in the lake.

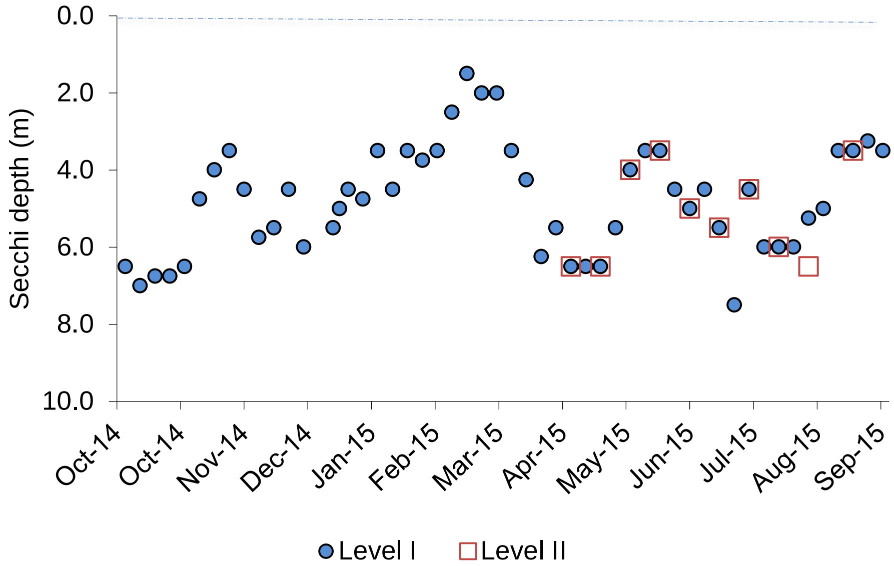


**Figure 18. Secchi depth for Lake Wilderness, water year 2015. Note the inverted Y-axis.**

## 5.3 Water Temperature

Lake Wilderness water temperatures in 2015 followed an expected seasonal pattern similar to other small lakes monitored through the Lake Stewardship Program, with cooler temperatures in the winter and spring, maximum temperatures occurring in late summer, and temperatures cooling by late September (Figure 19). Level I temperature data ranged from 5.0°C to 25.0°C through the year with an annual average of 14.7°C. Level II data, recorded from May through October, ranged from 15.5°C to 25.5°C, with a mean value of 21.0°C.

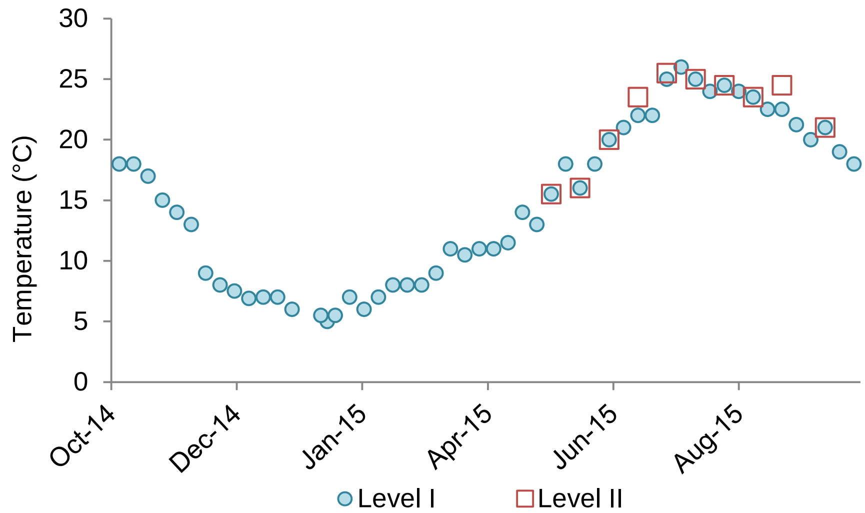


**Figure 19. Water temperature at 1 m for Lake Wilderness, water year 2015.**

The annual May-October average water temperature measured by Level II volunteers in 2015 was slightly warmer than in 2014 (Figure 20). Year-to-year variability is such that no trends are evident. When a linear trend line is applied to mean temperature data, an R-squared value of 0.0411 indicates a poor line fit for the data. Further monitoring will help determine if water temperatures in Lake Wilderness are changing over time.

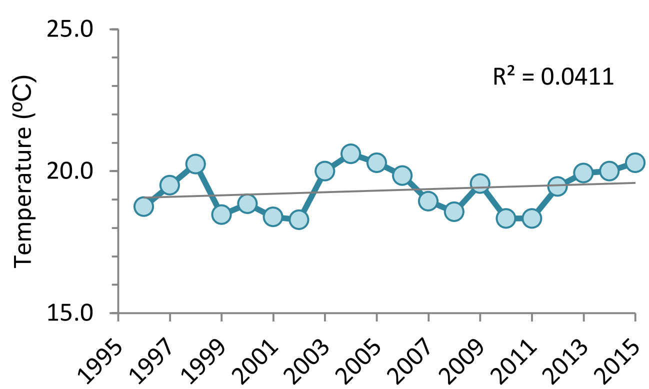


**Figure 20. Average temperature at 1 m for Lake Wilderness, May-October 1996-2015.**

## 5.4 Total Phosphorus and Total Nitrogen

Total phosphorus concentrations remained relatively stable in Lake Wilderness, while total nitrogen concentrations exhibited some fluctuation throughout the sample season (Figure 21). Total nitrogen peaked early in the sample season, and both nutrients exhibited increases through September and October. Total nitrogen values ranged from 248 to 763 µg/L, with an average of 427 µg/L. Total phosphorus concentrations ranged from 6.5 to 45.4 µg/L, with a mean value of 14.1 µg/L.

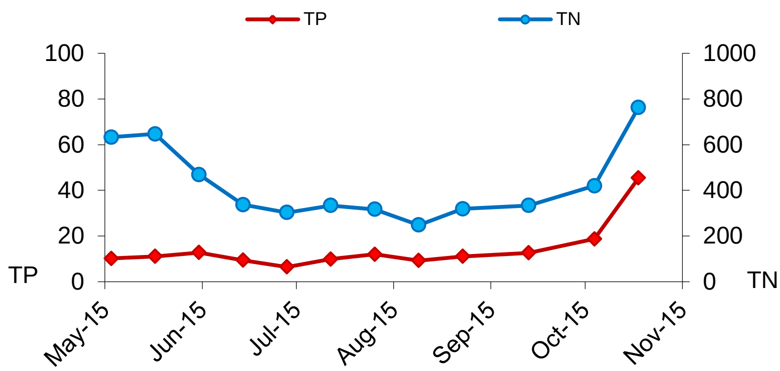


**Figure 21. Lake Wilderness total phosphorus and total nitrogen in µg/L, May-Oct 2015.**

The ratio of total nitrogen to total phosphorus in Lake Wilderness from May through October of 2015 ranged from 16.8 to 62.1, with an average ratio of 35.1 (Figure 22). Early in the sample season, ratios were far above 25, indicating that phosphorus was most likely the limiting nutrient during this time, and nutrient conditions were not favorable for cyanobacteria blooms. However, from late July onwards, N:P ratios remained near or below 25. These conditions indicate the nitrogen was likely the limiting nutrient, and conditions favored cyanobacteria blooms.

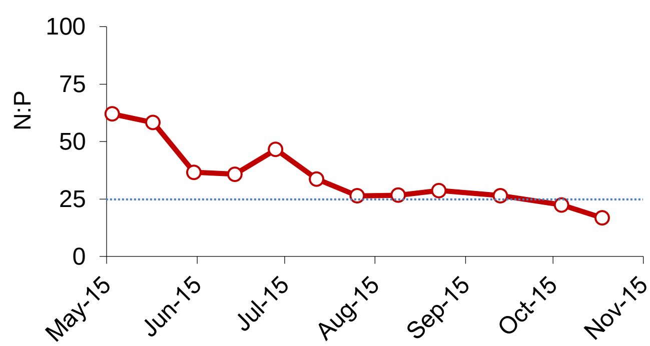


**Figure 22. Lake Wilderness N:P ratios, May-October 2015.**

Average May-October N:P ratios over time ranged from 16.8 to 45.7 in Lake Wilderness (Figure 23). When a linear trend line is applied to the data, there appears to be an increasing trend. The R-squared value of 0.7597 indicates that the line is a good fit for the data.

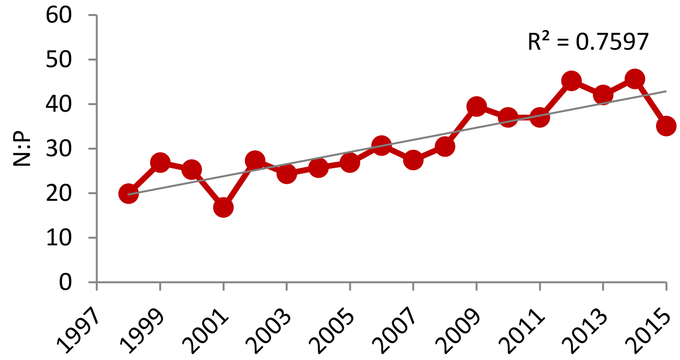


**Figure 23. Average May though October N:P ratios for Lake Wilderness since 1998.**

Lake Wilderness has experienced several toxic cyanobacteria blooms since toxin monitoring began there in 2008, with microcystin concentrations above the WA State Recreational Guidance threshold in 2009, 2010, 2013, and 2015. We recommend continuing to pay close attention to N:P ratios in Lake Wilderness, which have been increasing over time and favoring potentially toxic cyanobacteria.

## 5.5 Chlorophyll-*a*

Chlorophyll-*a* concentrations in Lake Wilderness exhibited large peaks in mid-June and again at the end of the sample season (Figure 24). These peaks correspond to decreases in Secchi depth, indicating that water clarity was likely affected, in part, by particulate algae in the water column. Chlorophyll-a concentrations were fairly low at other points during the season. concentrations ranged from 1.83 µg/L to 47.6 µg/L, with an average of 10.65 µg/L. Pheophytin concentrations remained below detection limits for the entire sample season, indicating that the samples were fresh and stored properly.

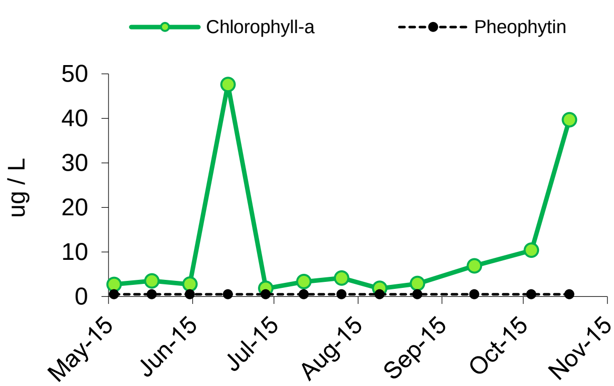


**Figure 24. Chlorophyll-*a* and pheophytin concentrations for Lake Wilderness, May-October 2015.**

## 5.6 Trophic State Indices

In 2015 the chlorophyll-*a* and total phosphorus trophic state indicators were in the mesotrophic range, and the Secchi indicator was in the Mesotrophic-Oligotrophic range for Lake Wilderness (Figure 25). The Secchi and TP indicators were very close together on the scale, indicating that the relationship between water clarity and the amount of nutrients in the water column were as the index would predict. The chlorophyll-*a* indicator was notably higher than the other two, signifying that the amount of algae in Lake Wilderness was higher than water clarity or TP concentrations would indicate.

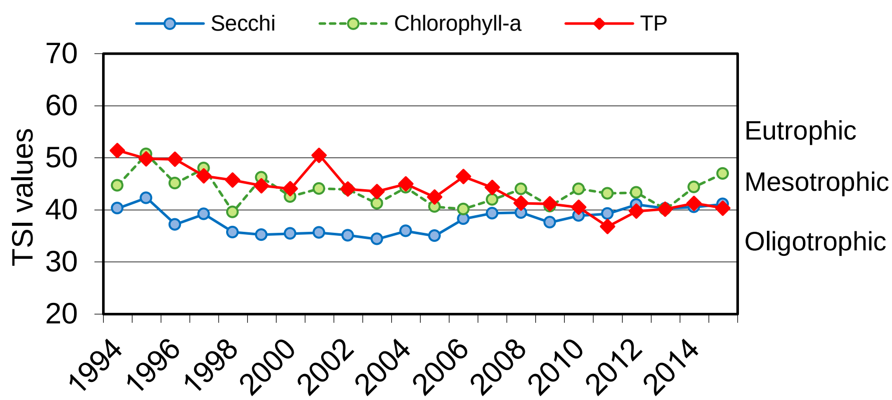


**Figure 25. Average May-October Trophic State Indicators for Lake Wilderness, 1994-2015.**

## 5.7 Water Column Profiles

Temperature data for Lake Wilderness indicate that thermal stratification (layering of warm, shallow water over cooler water at greater depth) was present in May and persisted through the second profile sampling event in late August (Table 3). Concentrations of total phosphorus were slightly elevated in the deepest sample for the May profile event, and were markedly higher in the August profile. Orthophosphate ($OPO_4$) concentrations exhibited a similar pattern indicating internal loading from sediment phosphorus released into the water column. Total nitrogen concentrations were nearly equal throughout the water column in May, but by the second profile, surface and mid-depth concentrations had decreased, while the bottom total nitrogen value was relatively high. Ammonia concentrations exhibited a similar pattern. Chlorophyll-*a* data indicate that algae were present in the water column, but at higher concentrations at depth. These patterns of profile nutrient and chlorophyll-*a* concentrations were similar to those observed in 2014.

**Table 3. Lake Wilderness water column profile results, 2015.**

| Date | Secchi | Depth | Temp | Chl-a | Pheo | TN | $NO_{2/3}$ | $NH_3$ | TP | $OPO_4$ | Alk | UV254 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/17/15 | 6.5 | 1 | 16 | 3.54 | *0.5* | 0.647 | 0.314 | 0.0276 | 0.0111 | 0.00057 | 42.6 | 0.0343 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4 | 16 | 2.93 | *0.5* | 0.618 | | | 0.0177 | | | |
| | | 8.5 | 10.5 | 15 | 3.3 | 0.661 | 0.242 | 0.205 | 0.0359 | 0.00693 | | |
| 8/23/15 | 6.5 | 1 | 16 | 2.94 | *0.5* | 0.319 | 0.242 | 0.0069 | 0.0111 | *0.0005* | 46.1 | 0.0438 |
| | | 4 | 16 | 2.71 | *0.5* | 0.334 | | | 0.0107 | | | |
| | | 8.5 | 10.5 | 115 | | 1.8 | *0.005* | 0.958 | 0.91 | 0.0746 | | |

Note: Temperature in degrees Celsius. Chlorophyll-*a* and pheophytin in µg/L. TN, $NO_{2/3}$, $NH_3$, TP, $OPO_4$, and alkalinity in mg/L. UV254 is in absorption units. Sample values below minimum detection level (MDL) are highlighted in red italics and have the value of the detection limit substituted.

UV254 is the wavelength at which dissolved organic molecules absorb light and is used to measure the amount of color in the water related to organic compounds. UV254 absorbance values in Lake Wilderness indicate that there was very little coloration from dissolved organic substances. Total alkalinity was moderately low, indicating that the water was only lightly buffered against changes in pH, and thus is potentially more sensitive to acidification.

## 5.8 Conclusions

Based on monitoring data, water quality in Lake Wilderness has fluctuated over the sampling years of 1994-2015, similar to the behavior of most aquatic systems in responding to multiple and diverse environmental variables. Measurements of physical and chemical parameters have shown both upward and downward variations from year to year.

Lake levels followed a pattern of winter highs and summer/fall lows, and there were no marked responses to precipitation events. Secchi depth readings were variable throughout the year, and TSI values for Secchi depth and total phosphorus indicate that water clarity was likely closely related to the amount of particulate matter in the water column. UV254 data collected during profile sampling events indicates that Lake Wilderness was very lightly colored by dissolved organic matter.

Water temperatures followed a very similar pattern to that of numerous other lakes in the region in 2015, exhibiting winter lows and summer highs. Average lake temperature was slightly higher than 2014, and a linear trend line applied to the data indicate the possibility of an increasing trend over time, though further monitoring is required to produce a more statistically viable trend. Profile temperature data show that Lake Wilderness was stratified in the summer and through the fall.

Chlorophyll-*a* concentrations were moderately low throughout the sample season, with the exception of large increases in early July and late October. The October bloom corresponded to increases of nutrients in the system. N:P ratios were near or below 25 from early August through the remainder of the sample season, indicating potential nitrogen limitation which created conditions favorable for excessive growth of blue-green algae.

Lake Wilderness has experienced several toxic cyanobacteria blooms since toxin monitoring began there in 2008, with microcystin concentrations above the WA State Recreational Guidance threshold in 2009, 2010, 2013, and 2015. We recommend continuing to pay close attention to N:P ratios in Lake Wilderness, which have been increasing over time and favoring potentially toxic cyanobacteria.

The long-term monitoring that the volunteers at Lake Wilderness have performed since 1994 has created an impressive and useful dataset that reflects the water quality story of the lake. Continued monitoring will help build this dataset, increasing our understanding of how the lake reacts to changes in weather and other influences on the watershed.